



Aalborg Universitet

AALBORG UNIVERSITY
DENMARK

CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 5

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

[Link to publication from Aalborg University](#)

Citation for published version (APA):
Heiselberg, P. K. (Ed.) (2016). *CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 5*. Department of Civil Engineering, Aalborg University.

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal -

Take down policy

If you believe that this document breaches copyright please contact us at vbn@aub.aau.dk providing details, and we will remove access to the work immediately and investigate your claim.

Influence of Supply Air Ceiling Diffusers on Surface Temperature of Display Cabinet Doors and on Customers Comfort in Food Stores

Onorio Saro^{#1}, Alessandra De Angelis^{#2}, Giovanni Cortella^{#3}

[#]*Department of Electrical, Management and Mechanical Engineering University of Udine
via delle Scienze, 208, Udine, Italy*

¹*onorio.saro@uniud.it*

²*alessandra.deangelis@uniud.it*

³*giovanni.cortella@uniud.it*

Abstract

Vertical display cabinets are widespread in food stores, because they have a large display area and an ease access for customers. Recently, open cabinets has been replaced with closed ones in order to reduce energy consumptions for refrigeration. However, the presence of the glass doors can have an effect on product visibility because of mist formation on the glass, particularly for low temperature display cabinets. This effect appears when the temperature at the external surface of the glass falls below the ambient dew temperature, which is a quite common situation in humid climate in the mid-season, when neither indoor air heating nor cooling is performed. Today the mist formation is prevented increasing the surface temperature at external side of the glass doors by means of electrical resistances embedded in the doors frame. The glass door surface temperature can be raised enhancing the heat transfer coefficient driving the supply air towards the display cabinet doors. This paper investigates the behaviour of different air ceiling diffusers (vortex diffusers and linear diffusers) in order to reduce the risk of mist formation and the energy consumption of electrical resistances. Initially, 3D numerical simulations of isothermal airflow field has been performed and, later, summer and winter conditions were considered.

The air flow field in the display zone, the temperature distribution on the glass surfaces and the influence of different diffusers on customers comfort condition are investigated.

Keywords - air diffuser; mist formation; display cabinet; CFD

1. Introduction

The most widespread refrigerated cabinets in food stores are open display cabinets, in which customers have a easy access to displayed products. This kind of cabinets are equipped with a cold air curtain in order to obtain a separation between the chilled air inside the cabinet and the hot ambient air of the store. However there is always an interaction between the air curtain and the environment causing a mixing of warm air from food store with cold air inside the cabinet. Part of this mixed air enters in the cabinet increasing its cooling requirement.

After all there is also a part of mixed air that spills out of the cabinet into the aisle of the food store, producing the “cold aisle effect”; this phenomenon is more intensified when cabinets are installed in opposed lines.

Open refrigerated cabinets equipped with air curtain have therefore two weak points (critical points) concerning the energy consumption of cabinets and the thermal comfort of the customers and staff.

Several researchers have studied both these points.

Howell and Adams studied effects of indoor space conditions on refrigerated display performance and found that the cooling demand depends strongly of infiltration of ambient air inside the cabinet.

Tassou and Xiang [1] investigated the influence of different methods of air management and heating on the cold aisle effect and found that reheating and supplying the withdraw air to the aisles from high level at low velocity and at a temperature almost equal to the air temperature in the store can improve thermal comfort and reduce energy consumption.

Due to concerns about energy consumption, chilled closed vertical cabinets are becoming more popular. Adding a door to the cabinet can reduce significantly the infiltration heat load. Fricke and Becker [2] compared a typical open refrigerated display case line-up to a typical glass-doored refrigerated display case line-up in order to quantify the energy consumption for each case. Tests were carried out simultaneously in two supermarkets similarly and located in the same climate, where they received either a new set of open-fronted or closed cabinets. They found that the open display cabinets consumed approximately 1.3 times more energy than the closed display cabinets.

Often closed cabinets needed anti-sweat heaters to avoid condensation on the glass surface and this increases the energy demand of the cabinet, but this addition is smaller respect to the reduction of energy requirement obtained adding the door to the cabinets. Lindberg et al [3] performed comparisons of measurements on vertical display cabinets with and without doors; tests shown that the addition of the doors reduce load from infiltration, lights and fans and even though there is an additional load due to anti-sweat heaters, the overall reduction in thermal load in closed cabinets was 73%.

A suitable air distribution system can reduce the risk of mist formation on the glass surface and, therefore, the electrical energy demand of the anti-sweat heaters, by means of two actions.

First, a lower humidity level of the ambient air reduces its dew point temperature and an HVAC plant allows to control the moisture content of the environmental air.

Second, driving the supply air towards the display cabinet doors allows to increase the convective coefficient on the glass; in this way the thermal resistance on the glass surfaces is lower and the surface temperature of the doors is nearer to air temperature reducing the risk of mist formation.

This latter aspect was numerically evaluated in the presented study.

2. Numerical simulations

2.1 Model geometry

The 3D computational domain used for the simulations is an aisle of a supermarket equipped with two vertical low temperature refrigerated cabinets; a sketch of the domain is shown in Figure 1.

Vertical cabinets are disposed on two lines, 12 meter length, overlooking the aisle, 4 meter wide. The plane of separation from the other zones of the supermarket has been located 2 m far from the end of the display cabinet lines; in this plane to model an open boundary a pressure outlet condition has been set. At the beginning, several domains are considered, with the plane at different distances from the end of the cabinets in order to verify that the position of this plane not affects the flow field in the interested zone.

Different supply diffusers are considered to evaluate the effects of the air distribution on the surface temperature of the glazed doors of the display cabinets. In the display zones of the supermarkets, usually based on open spaces, the air is supplied from the ceiling. Some more interesting ceiling diffuser are simulated:

- swirl circular diffusers: the air velocity has a vertical component and a radial component that can be changed varying the geometry of the diffuser;
- linear diffusers: long slots with deflectors to change the direction of the air flow.

These diffusers are characterized by a high vertical component of the mean air velocity.



Fig.1 Photo of simulated ceiling diffusers: vortex diffuser (a) linear diffuser (b)

2.2 Boundary conditions

The boundary conditions set for the CFD simulations are:

- prescribed temperature and mass flow rate for the supply inlet; the inlet air temperature was calculated in order to obtain an internal air temperature equal to 20°C in winter period and an internal air temperature equal to 26°C in summer period; the inlet volume flow rate was chosen on technical datasheet of the diffusers;
- prescribed temperature inside the vertical cabinets equal to -20°C for LT (low temperature) cabinets;
- heat transfer coefficient evaluated using the thermal characteristics of the cabinet door glass;
- pressure outlet on open boundaries, to allow reverse flows;
- no-slip condition on the ceiling, on the floor and on all other solid surfaces;
- symmetry conditions where applicable

In Table 1 the thermal boundary conditions for the display cabinet surfaces are reported.

Table 1. Thermal boundary conditions for LT cabinets.

	Glass	Opaque surfaces
Internal heat transfer coefficient [W/m ² K]	4.31	0.586
Air temperature inside cabinets [°C]	-20	-20
Emissivity [-]	0.8	0.8

2.3 Governing equations and turbulence model

The simulations are carried out using a numerical code based on the Finite Volume Method (Versteeg H., Malalasekera W., 2007). Initially, an isothermal airflow field is considered and, later, numerical simulations of the temperature distribution are carried out under summer and winter conditions.

The solver of the CFD-code relies on the classical segregated approach and the SIMPLE pressure-velocity coupling algorithm. The convective terms are integrated using the QUICK difference scheme, which produces a low level of numerical diffusion.

As in some regions of the room the air flow can be weakly turbulent the RNG variant of the k-ε model is used as the RNG theory provides an analytically-derived differential formula for effective viscosity that accounts for low-Reynolds number effects.

The fundamental equations consist of three differential equations represented in vectorial form:

the continuity equation

$$\partial p / (\partial \theta + \nabla \cdot (\rho \mathbf{w})) = 0 \quad (1)$$

the momentum equation

$$\partial (\rho \mathbf{w}) / (\partial \theta + \nabla \cdot (\rho \mathbf{w} \mathbf{w})) = -\nabla p + \nabla \mathbf{f} + \rho \mathbf{g} \quad (2)$$

the energy equation

$$\partial (\rho c_p T) / (\partial \theta + \nabla \cdot (\rho [\mathbf{w} \mathbf{c}])_p T) = \nabla \cdot (\lambda \nabla T) \quad (3)$$

3. Simulations Results

The air distribution considered in this study was a mixing ventilation, in which air is supplied by an air terminal device located at the ceiling. If the initial jet axis is close to the ceiling, jet flows along it and this is known as “Coanda” effect [4]. It was found [5] that if an edge of the nozzle was in contact with the plane, as long as the axis of the nozzle formed an angle less than 40°- 45° with the plane, the jet would cling to the plane and spread over it.

3.1 Vortex diffuser

The considered vortex circular diffuser is characterized by a variable geometry. The diffuser is equipped with six deflectors and the mechanism integrated into the hub allows to adjust the angle of deflection of the deflectors. The deflection angle can vary from 15° to 75° .

Figure 2 shows the path lines through the vortex diffuser and it can be noticed the swirling effect due to the shape of the wings. The effect of wing deflection on the air flow field can be seen also in Figure 3.

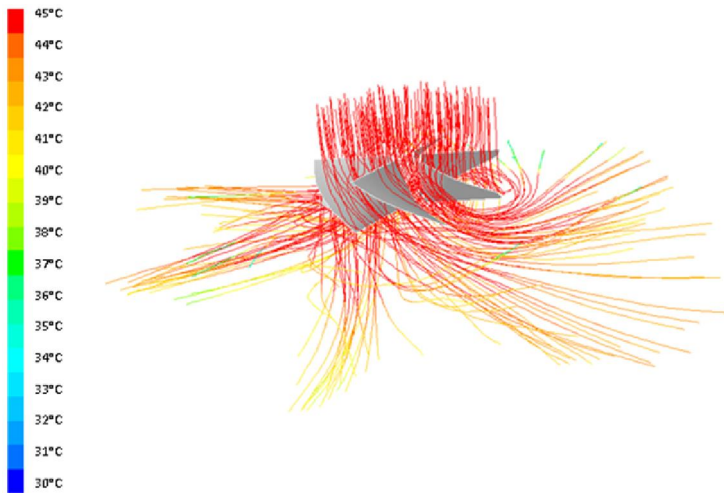


Fig.2 Path lines through the vortex diffuser with wing deflection of 45°

In the simulations on the vortex diffuser has been considered a non-symmetric computational domain due to the counter clock wise rotation of the swirl induced by the vortex diffusers. Figure 3 shows the velocity field on a vertical plane containing the vortex diffuser and highlights that there isn't a symmetric distribution of the air velocity field.

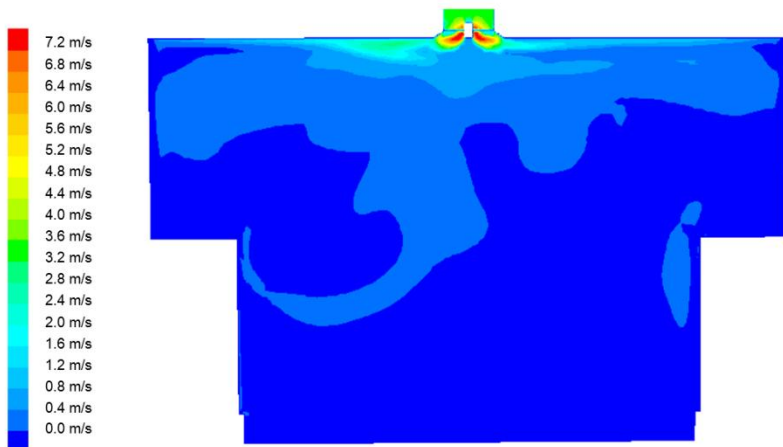
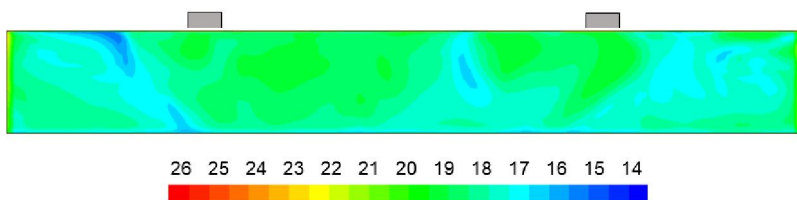
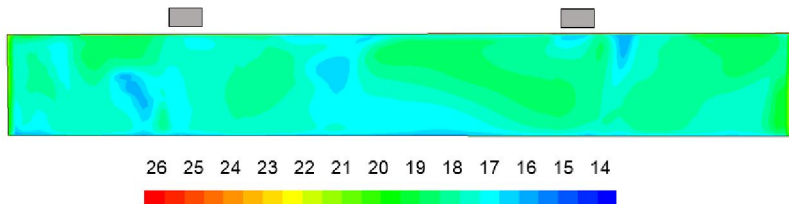


Fig.3 Velocity field (m/s) on the central plane of the aisle with air supplied by two vortex ceiling diffuser.

Moreover, the air velocity distribution on two glass door is quite different and this involves a strictly irregular air temperature distribution on glasses as can see in Figures 4.



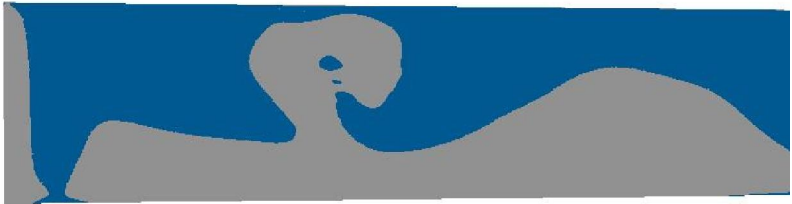
- a -



- b -

Fig. 4 Temperature distribution (°C) on the glass surface of the LT display cabinets located on the (a) right side (b) left side; the gray rectangles represent the position of the ceiling diffusers.

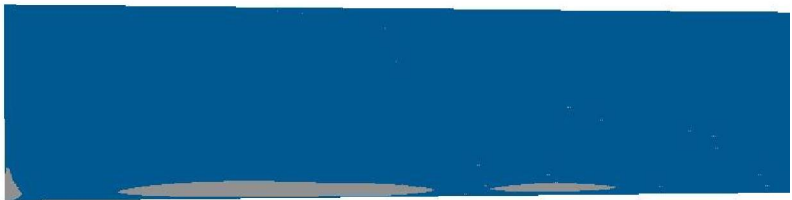
The areas with risk of mist formation can be derived from simulation results assuming the relative humidity in the display cabinets' zone. Figures 5 highlights in blue the glass surface areas with temperature below the dew-point temperature, assuming different values of relative humidity (50%-70%) in summer internal conditions (air temperature of 26°C). The higher is the relative humidity the wider is the extension of risk of mist formation with the vortex diffusers. It can be observed that, for LT cabinets' case, neither with a relative humidity of 50%, which corresponds to a dehumidified air, mist formation can be prevented by using vortex diffusers, mainly because of the non-uniform temperature distribution.



- a -



- b -



- c -

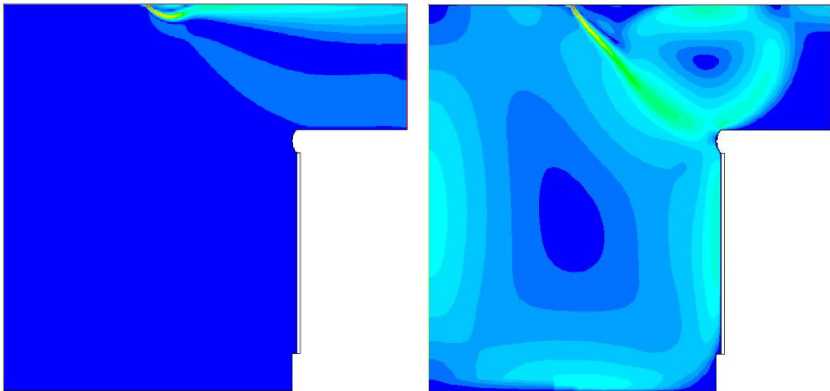


- d -

Fig. 5 Zones (in blue) below dew-point temperature in summer internal conditions (26°C) with the internal relative humidity of 50% (a), 55% (b), 60% (c), 65% (d) and 70% (e) on the glass surface of the chilled food LT display cabinets of half simulated domain.

3.2 Linear diffuser

The non uniform behaviour of the vortex diffuser led to choice of a linear ceiling diffuser extending to the whole length of cabinets. The numerical analysis involved different directions of supplied air flow: from 20° to 70° respect to the ceiling. Simulations showed that there is a “Coanda” (Figures 6) effect with angles up to 50°, but, for the aim of the present study, this effect is unwanted because the air jet doesn’t reach the glass of the door cabinets. Figure 7 shows the velocity field on the central plane (one of the two symmetry planes of the problem) resulting from the numerical simulations of the LT display cabinets’ zone with an angle of 60°.



- a -

- b -

Fig. 6 Velocity distribution (m/s) on the central plane of the aisle with an air jet direction of (a) 50° (b) 60° respect to the ceiling

A not investigated aspect in this study is the influence of the upper edge shape of the cabinet on air velocity distribution; this aspect will be examined in the progress of the study.

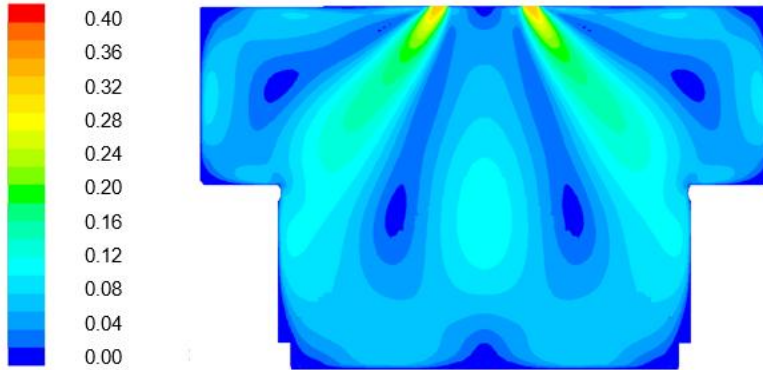


Fig.7 Velocity field (m/s) on the central plane of the aisle with air symmetrically supplied by two linear ceiling diffuser.

The velocity field shows as the supply air flows directly over the glass surfaces of cabinet doors. In this way the convective coefficient assumes higher values in comparison with to vortex air diffusers case. Higher convective coefficients reduce the thermal resistance on the glass surfaces and therefore the surface temperature of the doors is nearer to air temperature. In summer conditions the supply air temperature is lower than ambient temperature, but dryer, while in winter conditions the supply air is warmer than the ambient one and its humidity is higher. In both cases there is a compensation between temperature and humidity.

Figure 8 reports the temperature distribution on the glass surface of the LT cabinet doors in summer conditions. It can be appreciated the uniformity in horizontal direction. There is an evident vertical temperature gradient with a zone with high risk of mist formation. This risk can be mitigated rising the supply air velocity.

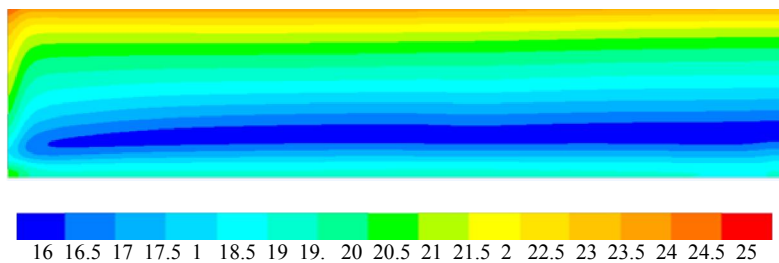


Fig. 8 Temperature field (°C) on the surface of the LT cabinet doors with air supplied by linear diffuser in summer conditions

Since there is a vertical gradient of the temperature distribution on glass of the cabinets, it's possible display condensation zones depending on height of glass. Figure 9 shows the height of zones below dew-point temperature in summer internal conditions with different internal air on the glass surface of display cabinets.

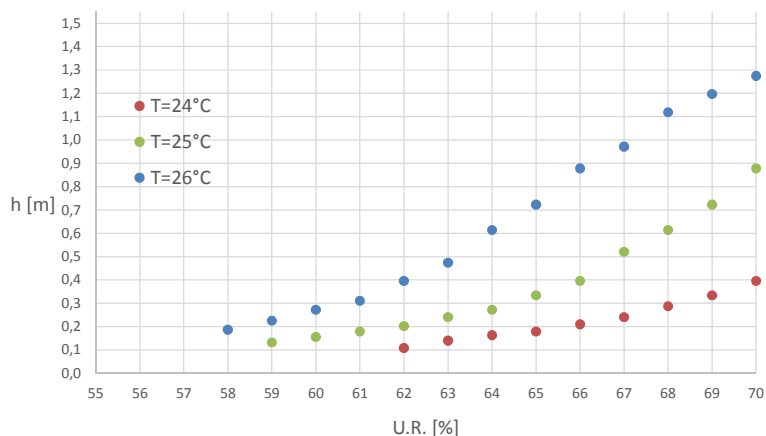


Fig. 9 Height of zones below dew-point temperature in summer internal conditions with different internal air on the glass surface of the chilled food LT display cabinets

The internal air humidity ratio in winter conditions assumes values lower than 50% and simulation results show that for these values there isn't mist formation on cabinets glasses.

4. Comfort conditions

Considering the values of velocity and temperature obtained from the numerical simulations, the effect on the global comfort is also evaluated. The graph in Fig. 10 reports the PMV calculated at three different distances from the floor on a plane at 50 cm in front of the display cabinets. The PMV is mostly between -0.25 and +0.25 which corresponds to a predicted percentage of dissatisfied (PPD) lower than 10%.

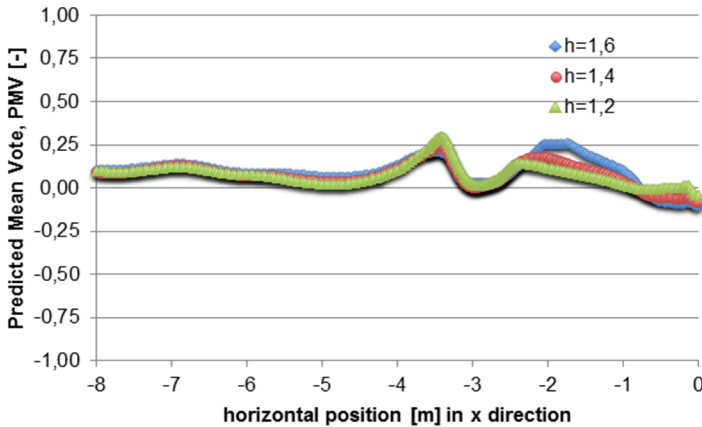


Fig. 10 PMV values at three different distances from the floor on a vertical plane at 0.5 m in front of the display cabinets with air supplied by vortex diffusers; the horizontal positions are negative owing to the orientation of the x axis

Fig. 10 PMV values at three different distances from the floor on a vertical plane at 0.5 m in front of the display cabinets with air supplied by vortex diffusers; the horizontal positions are negative owing to the orientation of the x axis.

In case of linear diffuser, air temperature and velocity assume values rather uniform along the x-direction, varying instead along the vertical direction. Therefore the PMV value practically doesn't change along the horizontal direction assuming values within the range [-0.09 – 0.05].

5. Conclusions

The supply diffusers shape affects the air distribution on the surface temperature of the glazed doors of the display cabinets. The heat transfer coefficient on the external surfaces of the display cabinets may be enhanced with a suitable distribution of the air particularly with high mass flow rate.

The air flow field in the display zone and the temperature distribution on the glass surfaces is evaluated for full-air HVAC system with different air supply diffusers by means of CFD analysis in order to predict and possibly to prevent the mist formation on the doors of closed display cabinets, avoiding the use of electrical resistances.

In conclusion, the temperature distribution on the surface of refrigeration cabinets' glass doors depend on the air distribution system. The presented CFD analyses on vortex and linear air diffusers lead us to the following considerations:

- in typical winter conditions the condensation risk on the glass doors of NT refrigerated cabinets' is practically absent when air is distributed within the cabinets' zone by means of vortex or linear air diffusers;
- in typical summer conditions there is a serious risk of condensation on the glass doors of LT refrigerated cabinets when air is distributed within the cabinets' zone by means of vortex air diffusers due to the non-uniform temperature distribution on the door surfaces;
- linear ceiling diffusers supply air flows directly towards the glass surfaces of cabinet doors allowing higher convective coefficient, lower thermal resistance and surface temperatures closer to the zone air temperature compared to the vortex air diffusers. In summer conditions the temperature distribution on the surface of the cabinet doors is more uniform in horizontal direction, reducing significantly the risk of condensation.

References

- [1] Savvas A. Tassou, Weizhong Xiang. Interactions Between the Environment and Open Refrigerated Display Cabinets in Retail Food Stores - Design Approaches to Reduce Shopper Discomfort. Ashrae Transactions, 109 (2003).
- [2] B. Fricke, B. Becker. Energy Use of Doored and Open Vertical Refrigerated Display Cases. International Refrigeration and Air Conditioning Conference, Purdue, (2010).
- [3] U. Lindberg, M. Axell, P. Fahlae. Vertical display cabinets without and with doors – a comparison of measurements in a laboratory and in a supermarket. IIR International Conference on the Cold Chain and Sustainability, Cambridge (2010).
- [4] Air velocity in ventilating jets. ASHRAE researches report No. 1467. ASHRAE Transaction Vol. 59, p.261, 1953.
- [5] Y. Huo, F. Haghighat, J.S. Zhang, C. Y. Shaw. A systematic approach to describe the air terminal device in CFD simulation for room air distribution analysis. Building and Environment 35 (2000) 563-5.